boilers of the Cornish and Lancashire types, and as, with gas, we have a fuel which renders every assistance to the experimenter, it will not take long to prove the comparative results obtained by the two different forms of web. Those of you who have steam-boilers will, no doubt, know the great liability to cracking at the rivet-holes in those parts where the plates are double. This cracking, so far as my own limited experience goes, being usually, if not always, on the fire side, where the end of the plate is not in direct contact with the water—where it is, in fact, under the conditions of one of the proposed webs—I think we may safely come to the conclusion that this cracking is caused by the great comparative expansion and contraction of the edge of the plate in contact with the fire; and it will probably be found that if the plates are covered with webs the whole of the surface of the plates will be kept at a higher and more uniform temperature, and the tendency to cracks at the rivet-holes will be reduced. This is a question not entirely of theory, but needs to be tested in actual practice.

There is another point of importance in boilers of the locomotive class, and those in which a very high temperature is kept in the fire-box, and this is the necessity of determining by direct experiment the speed with which heat can safely be conducted to the water without causing the evolution of steam to be so rapid as to prevent the water remaining in contact with the plates, and also whether the steam will or will not carry mechanically with it so much water as to make it objectionably wet, and cause priming and loss of work by water being carried into the cylinders. I have observed in the open boilers I use that when sufficient heat is applied to evaporate 1 cubic foot of water per hour from 1 square foot of boiler surface, the bulk of the water in the vessel is about doubled, and that the water holds permanently in suspension a bulk of steam equal to itself. I have, as yet, not had sufficient experience to say anything positively as to the formation or adhesion of scale on such surfaces as I refer to, but the whole of my experimental boilers have up to the present remained bright and clean on the water surface, being distinctly cleaner than the boiler used with ordinary flat surfaces. It is, I believe, generally acknowledged that quick heating and rapid circulation prevents to some extent the formation of hard scale, and this is in perfect accord with the results of my experiments. The experiments which I have shown you I think demonstrate beyond all question that the steaming-power of boilers in limited spaces, such as our sea-going ships, can be greatly increased; and when we consider how valuable space is on board ship, the matter is one worthy of serious study and experiment. It may be well to mention that some applications of this theory are already patented.

I will now show you as a matter of interest in the application of coal gas as a fuel how quickly a small quantity of water can be boiled by a kettle constructed on the principle I have described, and to make the experiment a practical one I will use a heavy and strongly-made copper kettle which weighs 6½ lbs., and will hold when full one gallon. In this kettle I will boil a pint of water, and, as you see, rapid boiling takes place in 50 seconds. The same result could be attained in a light and specially-made kettle in 30 seconds, but the experiment would not be a fair practical one, as the vessel used would not be fit for hard daily service, and I have therefore limited myself to what can be done in actual daily work rather than laboratory results, which, however interesting they may be, would not be a fair example of the apparatus in actual use at present.

THE CRATERS OF MOKUAWEOWEO, ON MAUNA LOA[1]

DURING last year I was engaged for many months in surveying lands on Mauna Hualalai and Mauna Loa, in Hawaii, and in that way had an opportunity of making investigations of craters and lava flows that may be of interest to those studying volcanic phenomena.

It would seem that, as the best histories are those written long after the events which they record, when all the reports of eye-witnesses can be carefully examined, so the best descriptions of volcanic action may be obtained long after eruptions, by carefully investigating the records indeliby inscribed in the rocks.

The ascent of Mauna Loa is so seldom made that a brief account of my excursions may be interesting.

[1] By J. M. Alexander, from the *Hawaiian Commercial Advertiser* of October 1885.

On September 1, 1885, I set out in company with Mr. J. S. Emerson, of the Hawaiian Government Survey, to ascend that mountain from the table-land east of Hualalai, along the south side of the lava-flow of 1859, which, as many will remember, was visited by a party from Oahu College. We were provided with mules for riding and pack-donkeys, and accompanied by several natives, including a so-called guide, who lost himself and delayed us over a day in searching for him.

Our route led first through a narrow belt of forest, consisting of mamane, ohia, and sandalwood trees; then through a scanty vegetation of ohelos and the beautiful *Cyathodes Tameiameiæ*, and at last beyond the limits of vegetation, without a vestige even of moss or lichen, over a wonderful and awful billowy waste of "pahoehoe" lava, traversed by tracts of "aa" and deep chasms.

At about two-thirds of the distance towards the summit we passed the rugged crater hill from which the outbreak of 1859 had issued, and here our path was strewed with pumice and "Pele's hair" from that eruption. There was an enormous quantity of lava poured forth from the small fissure of this crater, forming a stream from half a mile to two miles wide, and reaching nearly thirty miles to the ocean at Kiholo. Lower down I counted eighteen species of ferns and a dozen kinds of phenogamous plants already growing on this flow. In this vicinity the caverns contained many carcasses of wild goats. In one further south I counted eighty of their skeletons and decaying bodies. They had probably leaped in for shelter, and had been unable to leap out.

When near the summit our guide warned us to descend, because of an approaching storm; but Mr. Emerson and I, anxious to accomplish the object of our journey, set out without him through the driving rain that soon turned into hail and then into snow, marking our route with flags so that we might be able to find our way back. In a short time we reached the brink of the vast crater of Mokuaweoweo, filled with fog and surrounded by frightful precipices. Along this brink were numerous deep fissures filled with ice and water, the beginning of cleavage for avalanches into the crater. Here, and for a quarter of a mile below, we observed many rocks of a different kind from the surface lavas, solid, flinty fragments of the foundation walls, weighing from fifty pounds to a ton, which had formerly fallen down upon the crater floor and had afterwards been hurled out during eruptions. I noticed similar rocks around the summit craters of Hualalai. It would be unsafe to approach the crater at this place during eruptions, when such brickbats were flying.

We returned to our camp about noon, and sent the poor animals, which had stood all night in the icy wind tied to jagged rocks, in the care of the guide down the mountain; and with the help of one native, with much difficulty, carried a tent and supplies to the summit.

At evening the fog lifted and gave us a glimpse of the craters. Immediately below us lay the central crater, surrounded by almost perpendicular walls, with a pahoehoe floor streaked with grey sulphur cracks, from hundreds of which there issued columns of steam, and with a still smoking cone in the south end. Beyond this central crater on the south rose a high plateau, and beyond this plateau still further south we saw an opening into another crater small and deep. In the opposite direction, north of the central crater, appeared another higher crater like an upper plateau, from which a torrent of lava had once poured into the central crater, and north of this again another crater, like a still higher plateau, from which also lava had flowed south.

Thus it was evident, as appeared more clearly by subsequent investigation, that Mokuaweoweo is not simply one crater, but a series of four or five craters, the walls of which have broken down, so that they have flowed into each other.

The crater of Haleakala, on Maui, was probably formed in a similar manner out of several ancient craters which have broken into each other. These vast chasms may well be called calderas, as has been recommended by Captain Dutton. On Hualalai there is a series of craters having the same relative position as those of Mokuaweoweo, and crowded so close together as to be almost broken into one. On the older mountains, like that of West Maui, such congeries of craters have evidently formed the starting-points for deep valleys, which the rain torrents, leaping down their lofty walls, have torn out through concentric layers of lava to the sea. Just before sunset we saw the splendid phenomenon of the "Spectre of the Brocken" (Hookuaka),

our shadows on the mist, encircled with rainbows, over the black inferno.

We erected a survey signal for determining the location and height of the summit, and also of an important land boundary in the crater, viz. the corner where the four lands of Keauhou, Kahuku, Kapapala, and Kaohe meet, which is at the cone in the central crater. We then descended the mountain, carrying more weight than was agreeable, until we were met by our natives bringing up our mules, for which we had signalled by fires. On the way down a violent thunderstorm was raging below us, while we were above in clear air. On my next trip up this mountain I found a tree on the slope below completely rent to splinters, and parts of it thrown several rods, by the lightning of this storm.

During the next month I ascended the mountain again, this time carrying an excellent engineer's transit. As I had no guide, I marked most of the way up by strips of cloth fastened to rocks to find the way back; and taught by our former experience, I took a donkey-load of fuel, as well us a load of grass for making a spherical survey signal, which served me several nights as a bed. When about half-way up the mountain, one of our pack-donkeys broke into a lava cave, and slid downwards nearly out of sight. It was extricated with great difficulty by a direct upward lift with ropes. I then sent one of my men down the mountain with the donkeys, retaining the other man with me. The first night on the summit was uncomfortable enough for us, with a storm from the north. At midnight we observed with a lighted candle that the roof of the tent was a-sparkle with icicles, and on touching it found it frozen stiff as a bullock's hide. In the morning we found a beautiful sheet of snow an inch thick over the tent and over all the ghastly blackness of the rocks. Every morning of our stay upon the mountain we found the water frozen in our kettles, and hoar-frost on the rocks.

In the clear frosty air I was able with my transit to take the bearings of a dozen survey signals on the slopes and summit of Hualalai.

The new spherical signal which I had erected was afterwards accurately determined by observations from more than twenty stations on Mauna Kea, Hualalai, and in South Kona, and thus a trigonometrical station was at last located on the very summit of Mauna Loa.

On the second day I descended from the west brink of the crater down the track of a high avalanche of rocks upon the second plateau, and again from this plateau by the path of another avalanche into the central crater, stepping cautiously down upon the black floor of the crater, lest it should break under our weight. We found this caution unnecessary, for much of the crater bottom proved to be the most solid kind of pahoehoe.

Here we stood as on the congealed surface of a tossing sea that had dashed its fiery surf thirty feet up on the surrounding walls. We travelled directly south for the cone, the boundary corner, which I was to locate, erecting two flags about 2500 feet apart for the ends of our base-line. In some places, where there appeared to have been violent action, the lava broke under our feet, letting us down into caverns. In some large tracts the pahoehoe was covered with pumice, indicating the violence of the former surging and tossing of the lava, for pumice and other light lavas seem to be the froth and foam of the fiercest eruptions. Just before reaching the cone we came to a deeper basin, twenty or more feet below the rest of the crater bottom and about 400 feet wide, covered with the most friable lava, swollen upwards as though raised by air-bubbles, and this basin extended in a lava flow to the north-east along the side of the crater.

Probably this was the place of the last eruption, and of most of the eruptions of this central crater. We found the cone to be composed of pumice and friable lava still hot and smoking, and very difficult to ascend, but we succeeded in climbing to its top, 140 feet high, and in setting up a flag there for the boundary corner. We then descended between the east and west peaks of this cone over huge rocks and deep chasms.

From the fact that this cone is represented on Mr. J. M. Lydgate's map of 1874, I conclude that it has been of long continuance, probably composed of the cinders of successive eruptions, and that the deep basin to the windward of it, like Halemaumau in Kilauea, has continued many years, and is situated at the great central volcanic throat of the mountain.

I then returned to the second plateau to the north, and thence clambered out to the east of Mokuaweoweo by the extremely interesting route of a former cataract of lava from the summit into the crater, the swift downfall of which had turned its lava almost into pumice, and the black, shining spray of which lay spattered on the surrounding rocks.

Further south I observed the course of two other cataracts, which had poured directly into the central crater. At the summit I found the deep fissure from which the outbreak had come that caused these cataracts, and ascertained that it had also poured an immense stream north upon the first plateau and thence south to the central crater. Crossing from this place to the north over the first plateau I suddenly came to a frightful circular crater in the bed of the plateau, apparently 600 feet deep and 1000 feet wide, with a cone in its centre still smoking. We were obliged to hurry with exhausting speed over rough lava in order to reach our tent before night.

The next day we took the transit to the stations in the crater, and the next we surveyed with it along the western brink to the extreme south end, where we looked down into the south crater, which is about 800 feet deep and 2500 feet wide. The length of the whole chasm, or "caldera," I have ascertained to be about 19,000 feet, the greatest breadth 9000 feet, and the greatest depth 800 feet. The area is three and six-tenths square miles. A map of these craters has been sent to the Government Survey Office.

On the south-west side, near the junction of the central crater with the south plateau, I found that there had been another eruption, from fissures that were still smoking, and that this eruption had poured an immense stream southward towards Kahuku, and had also poured cataracts into the south crater from all sides.

I had everywhere observed that there had been great flows from the summit brink down the mountain, and had wondered at the thought of the vast chasm having filled up and overflowed its brim.

This, however, turned out to be an incorrect view. The flows have not been from the lowest parts of the brim, but from some of the highest, which could not have been the case in an overflow.

The walls of the craters are largely composed of loose, old, weather-beaten rocks, and large tracts of the plateau are composed of old pahoehoe that has not been overflowed for ages, which would not be the case if the craters filled and overflowed.

These outbreaks from fissures around the rim indicate that the lava has rather poured into the crater than out of it; and that it has poured from such fissures in vast streams down the mountain-side. What enormous quantities of lava may flow from such small fissures is illustrated by the flow of 1859. The question arises, How has the lava risen high enough to pour in extensive eruptions through these fissures, almost a thousand feet above the bottom of the crater, without rising in the crater and overflowing it? The same question has often been asked in respect to the rise of liquid lava to the summit of Mauna Loa without overflowing the open crater of Kilauea, 10,000 feet below.

We have seen that it is not because the lava in Mokuaweoweo is lighter than that in Kilauea that it rises so much higher. In fact, it is as solid there as in Kilauea. The explanation has occurred to me that molten lavas rise the higher the smaller the conduits in which they rise from their subterranean reservoirs.

An illustration is afforded by the "spouting horns" on the sea-coast, where the ocean, rushing into caverns of rock, drives columns of water through small openings to the height of forty or fifty feet above high-water mark. We see another illustration in water conveyed in pipes, which jets the higher the smaller the orifice.

However violent the subterranean pressure may be, Kilauea does not overflow, but only rages the more fiercely, because its passage from the chambers below is so large. But through the vast mountain of Mauna Loa there is no doubt a constricted conduit leading upward; and there must be still smaller conduits to the fissures on the summit rim. On this theory, the molten lava rises higher through Mauna Loa than in Kilauea, because Mauna Loa has the smaller throat.

It is therefore by no means certain that there is no subterranean connection between the two volcanoes.

Another vexed question, of which several solutions have been proposed, is the mode of formation of the two strongly contrasted forms of lava known as "pahoehoe" and "aa." The former term is applied to tracts of comparatively smooth and uniform lava, as though it had cooled while flowing quietly; the latter to tracts of broken lava, as though it had cooled when tossing like an ocean in a storm, and had then been broken up by earth-

quakes. As Mr. Brigham states, "No words can convey an idea of its horrible roughness and hardness."

My own belief is that "aa" has been formed simply by obstructions breaking the quiet flow of molten lava. Every observer has noticed that "pahoehoe" contains ducts and air-chambers, having an upper crust contorted into the shape of the waves and ripples of the flowing lava. The liquid lava has evidently flowed in these ducts and chambers, and at last flowing out has left them empty with glazed interior surfaces. In like manner torrents of lava have poured through caverns down the mountains to the sea, and flowing out have left the innumerable caves, smooth and shining within, to be found all over the island. Now, when there are obstructions on the earth's surface or meeting flows, this system of ducts is broken up, and fragments of lava are carried along on the surface, piling up higher than the adjacent "pahoehoe," like ice-packs in rivers, and sometimes rolling immense boulders twenty and thirty feet high, which now stand on the "aa" with the drip glistening over them. This theory is confirmed by the fact that "aa" is always higher than the adjoining "pahoehoe," and also by the fact, which I especially noticed in the flow of 1859, that wherever there are open spaces in lava flows (kipukas), the old lava under the flow is found to be "pahoehoe" under "pahoehoe" and "aa" under "aa."

While surveying the region I was extremely interested in the arrangement of the craters; and now having determined the situation of more than fifty of them on Mauna Loa, Hualalai, and Mauna Kea, I have ascertained that there is a method in their arrangement. They are not arranged relatively to the mountain on which they are situated, but relatively to the points of the compass. There seems to have been a series of nearly parallel fissures through which these craters have risen, in lines running from S. 40° E. to S. 60° E. There are a few arranged in lines running N. 50° E.

It has been remarked by Mr. W. T. Brigham that, while the general trend of the Hawaiian group and of the major axis of each island is N. 60° W., there is no crater on the islands whose major axis is parallel to this line. "On the contrary," he continues, "a very interesting parallelism is observed among all the craters, and invariably the longest diameter is north and south." It would be more correct to say that the major axes of the great craters are generally at right angles to the general axis of the group, *i.e.* about N. 30° E. Haleakala and the ancient Kipahulu caldera appear to take the other direction, but the statement is certainly true of the great calderas of Kilauea and Mokuaweoweo, which have other points of resemblance.

Thus in both the highest walls are on the western side, and in both the action is working towards the south-west, as is indicated by the fact that the north-east craters are nearly filled up, while the deepest and active craters are in the south-west end of the caldera.

It has been shown by Prof. Dana and other geologists that the principal mountain-ranges of the globe, as well as the main coast-lines and chains of islands, take the two directions just mentioned, "which are in general tangential to the Arctic and Antarctic circles." Thus it appears that the laws in accordance with which the volcanic forces are now operating in these islands are the same as those by which all the grand features of our world have been established, and possibly related to the laws of crystallisation which pervade the mineral kingdom; and thus we perceive a unity in the processes of the globe.

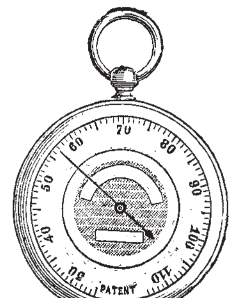
In conclusion, I would remark that to my mind the most plausible theory to account for volcanic action is that of Mallet, that the contraction of the earth's crust continually going on under the power of gravitation causes as much internal heat as would be required to cause a similar expansion. Prof. Dana has remarked that "the fact is well established that motion in the earth's rocks has been a powerful source of heat," and that the annual crushing of not over one-sixth of a cubic mile of rocks in the earth would cause all the volcanic phenomena of the world. This theory has the beauty of attributing all these phenomena to a single cause, and of thus suggesting the thought of the one great Power above the inexplicable forces of gravitation, who continues all the forces of the universe.

IMMISCH'S THERMOMETER

THIS instrument depends for its action upon the opening and closing of a minute volute Bourdon tube, which for this purpose is filled with expansive liquid and hermetically sealed. One end of the tube is fixed, and the free end is brought into contact with the short arm of a lever, the long arm of which forms a rack gearing with a pinion which carries the pointer. The position of the tube with regard to the short lever-arm is such that for ordinary purposes the divisions on the dial are equal, while for clinical use the scale is an increasing one, in order that near blood-heat the divisions become wider to permi of a fraction of a degree being read off accurately.

The success which these instruments meet with is owing principally to their sensitiveness, accuracy, and non-liability to get broken. If they should meet with an accident they can be easily repaired.

The appellation "metallic" does not seem to be a happy one for these thermometers, as they are likely to be confounded with the unsuccessful attempts which have been made to produce instruments for similar purposes by means of bi-metallic laminæ. The defects of the latter are the extremely small *vis viva* avail-



able for the work of multiplying the small motion of the laminæ, and the liability to not return to precisely the same point after being subjected to extremes of temperature. In this latter respect there is a double security with the instrument which is the subject of this notice. The tube is in itself a very flexible spring, the motion of which does not overreach the limits of perfect elasticity, and its position at any given time is determined by the volume of the liquid, which, of course, remains always a constant quantity whatever the volume may be. As the tube is absolutely full, it must of necessity always accommodate itself to the volume and correctly indicate the temperature.

As regards accuracy, we are informed that upwards of 500 have already been tested at Kew—we have ourselves seen the certificates of the last group of two dozen clinical ones, and they give the remarkable results of perfect accuracy at 66 per cent. of the points tested, and of no error greater than 0°·2 at any point on any one of the twenty-four thermometers.

SCIENTIFIC SERIALS

Rendiconti del Reale Istituto Lombardo, May 13.—On the theory of waves, by Prof. E. Beltrami. The author presents some considerations which place in a clearer light the process by which F. Neumann deduces the laws of Fresnel from the fundamental equations of elasticity.—Dynamics of moving systems which preserve their mutual affinity, by Prof. C. Formenti.

Rivista Scientifico-Industriale, May 31.—Maximum and relative humidity of the atmosphere, by Prof. Paolo Cantoni. Hygrometric tables of mean annual moisture, recorded at thirty meteorological stations in various parts of Italy, show that the average of maximum and relative humidity increases from north to south, from elevated to low-lying stations, and from inland to maritime districts.—On the persistence of the mathematical figure of the earth throughout the geological epochs, and on the constitution of the terrestrial crust, by Prof. Annibale Riccò. A summary is given of M. H. Faye's views on this subject already published in the *Comptes rendus* of the French Academy (March 22 and April 5, 1886), the author concluding that the mathematical figure of the globe, as represented by the surface of oceans, has not been perceptibly modified by the geological forces associated with the cooling process.—On the permanent magnetism of steel at various temperatures, by Prof. Poloni. It is shown that at the temperature of 180° C. the well-known law of magnetic distribution in steel bars no longer holds good when